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Introduction

Aquarium experiments with weak electrical stimulation demonstrated that flatfish could be induced to move away from electrified zones (Stewart, 1973). This response suggested that an electric stimulus could be used as an aid to capture and might possibly replace the use of chain 'ticklers' on trawls. Direct observations on the reactions of flatfish of the Pleuronectidae (mainly plaice, *Platessa platessa,* and the common dab, *Limanda limanda*) to electrical stimulation were made in Burghead Bay by towing over the sea bed a manned sledge supporting an energised electrode array (Stewart, 1977). The electrical stimulus was pulsed DC, ranging in frequency from 4 to 40 Hz. Involuntary muscular contractions were induced by this stimulus, which caused the majority of fish to move away from the electrified area. The results suggested that the most efficient frequency for inducing these species to leave the bottom is around 20 Hz, and that large fish are more strongly stimulated by an electric field than small fish. Both continuous and intermittent stimulation were found to be effective, but it was considered that the continuous stimulus would be less effective when used on a fishing gear as it tended to immobilise the fish in the energised zone for several seconds.

To investigate the reactions of flatfish to an electrified gear an experiment was conducted with a 3 m beam trawl attached to each side of the manned sledge, one side having electric ticklers and the other, for comparative purposes, having a chain tickler (Stewart, 1976). The trawls were towed over the bottom and divers on the sledge were able to observe how flatfish reacted to the combined stimulus of a net and a tickler system. The fish forced out by the chain were herded by it for considerable distances until they either dropped back into the net or accelerated ahead and escaped. Behaviour of this type has been reported by Hemmings (1973). On the electrified side the fish were induced to move off the bottom by the electric stimulus. They then attempted to swim ahead of the groundrope, but this zone was rendered inhospitable by the electric field. The fish reacted by dropping back into the net immediately, by swimming rapidly from side to side of the net as far above the electrodes as possible for up to 30 seconds and then turning back into the net, or by escaping under the footrope. No fish were seen to escape from the front of the electrified trawl. This indicated that this type of electrified gear was potentially very efficient, provided that the escape of flatfish under the groundrope could be eliminated either by weighting it more heavily or by rigging a small chain in front to obscure it with a mud cloud.

These observations indicated that electrical stimulation on a fishing gear could be effective in forcing flatfish off the bottom and could act selectively on larger fish. The next stage in the programme was the testing of an electrified flatfish gear at sea to check that these effects could be obtained under fishing conditions. This report describes a series of comparative fishing experiments with an electrified beam trawl. The study was conducted in two parts. The catch obtained using an electric tickler system was compared firstly with the catch obtained without any tickler system and secondly with the catch obtained using a chain tickler. The first part of the experiment was conducted to check that electric ticklers had a measurable effect, and the second to determine the relative efficiency of the electric ticklers and their influence on the size composition of the catch.

A divided beam trawl was used for the experiment. The beam trawl is a suitable gear for flatfish but, as the work was carried out on the fishery research vessel 'Clupea' — a side trawler — it was possible to use only one beam in the experiment. Comparative fishing experiments are best conducted by the simultaneous towing of the gears to be compared. To achieve this on a single beam trawl the net was divided from the beam aft to twin codends. The tickler systems being compared in each haul were rigged in the two halves of the gear. The beam trawl has advantages for electrical fishing as it provides a sturdy framework to support net-mounted pulse generating equipment and an electrode array.

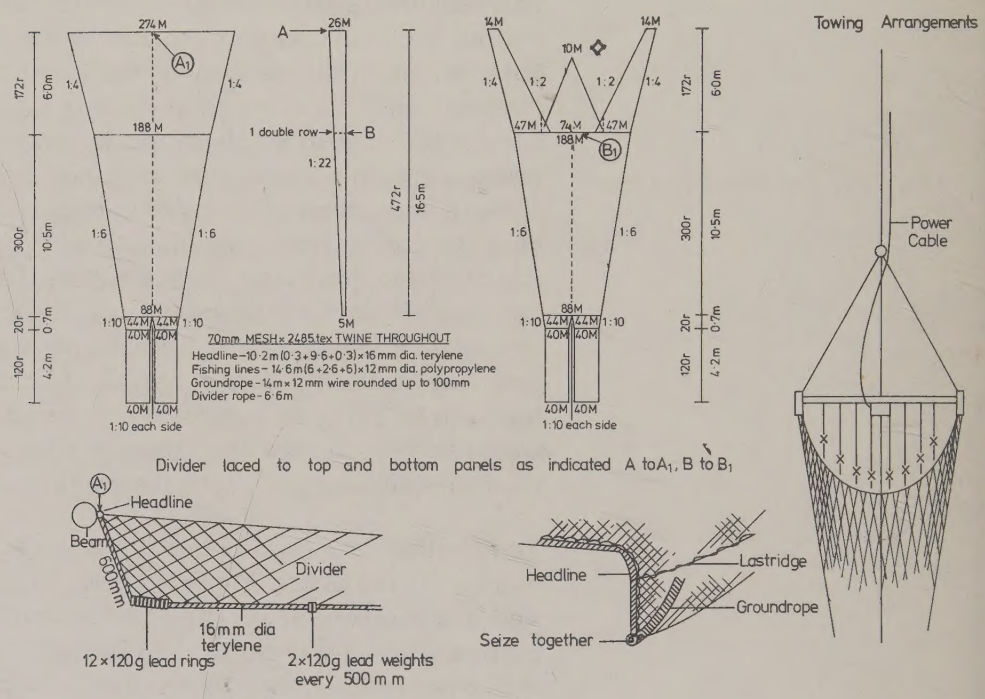

Figure 1. Beam trawl net and towing rig.

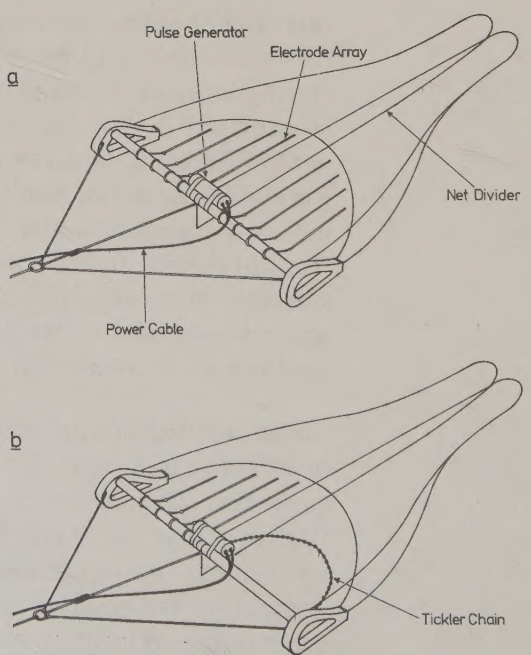

Figure 2. Beam trawl showing electrical system and ticklers used in experiments to compare catches taken

a) with and without electric ticklers, and

b) with electric and chain ticklers.

Equipment and experimental methods

Fishing gear

A 9 m beam trawl was used for the experiments. The gear is shown in Figures 1 and 2. Figure 1 shows the net and towing rig, and Figure 2 the beam and the electrical system, in 2a as rigged for the first part of the experiment, and in 2b as for the second part. The section of the net divider in front of the groundrope was weighted to keep it in contact with the sea bed. The groundrope was 12 mm wire rounded up to 100 mm with rope and weighted with chain. The towing rig was a double bridle with a slack centre strop for emergency use. The bridle was attached to a single towing warp and the gear was shot and towed from the fore gallows. The beam trawl shoes each weighed approximately 60 kg and the beam was constructed from three interlocking sections of steel pipe.

In the second part of the experiment one side of the gear was rigged with a single length of 12 mm chain, which the earlier observations by divers had shown to be effective in forcing flatfish such as plaice and common dab off the sea bed.

Electrical system

The electrical system used in this experiment was identical to that used in a previous comparative fishing experiment for *Nephrops norvegicus* (Stewart, 1975). Power at 50 Hz was transmitted from the towing vessel via an armoured cable to the pulse generator mounted on the centre of the beam. The pulse generator was controlled from the surface and delivered the required electrical stimulus to the electrode array. The stimulation pattern used in the experiment was 1 second long bursts of 20 Hz DC pulses with 1 second intervals between bursts. The voltage developed between the electrodes was monitored continuously and found to be 50-60 volts. Each electrode array consisted of four lengths of 1 cm diameter stainless steel warp. The separation between the electrodes was 1 m and they were attached to the beam and the groundrope with short lengths of rope to keep them in fixed positions.

Experimental procedure

Trawling was carried out on the fishery research vessel 'Clupea'. The first part of the experiment was conducted in the Moray Firth and on Turbot Bank in June 1974 and the second part in the Moray Firth in October 1975 and October 1976. In the first part each side of the gear was equipped with an identical electrode array and the side to be electrified was chosen at random. In the second part one side had an electrode array and the other a chain tickler. Since the changing of these systems was time consuming, the rigging was changed once only, in the middle of the October 1975 cruise. Tows lasted for between 60 and 90 minutes and after each haul the catch was counted and measured. The towing speed was normally 1–1.5 m s^{-1} (approx. 2 to 3 knots). A haul was considered to provide a valid comparison if the gear was undamaged at the end of the tow and if the electrical system functioned correctly for the whole tow.

At the beginning of each cruise the gear was inspected by divers to check that it was correctly rigged, particularly the electrode array, and that it was towing evenly. These inspections were carried out in the Dornoch Firth in water 20 m deep.

Results

The catches consisted mainly of plaice *Pleuronectes platessa,* the common dab *Limanda limanda* and lemon sole *Microstomus kitt.* In the first cruise some skate *Raja naevus* and juvenile Dover sole *Solea solea* were also caught. The catch obtained in the first part of the experiment during June 1974 is presented in Table I and Figure 3. Table I presents the total catch data for the cruise showing the catches obtained in each haul and the side of the gear electrified. In Figure 3 the catch length data for plaice, common dab and lemon sole are presented.

Table I

Number of fish caught in successive hauls in the Moray Firth and on Turbot Bank during June 1974 (non-electrified catch in bold type)

Haul No	Side Electritied	Lemon Sole		Plaice		Common Dab		Skate		Dover Sole	
1	Stbd	18	**14**	20	**11**	130	**79**	-	-	-	-
2	"	13	**7**	8	**8**	66	**64**	-	-	1	**0**
3	"	31	**26**	3	**1**	28	**33**	3	**0**	1	**0**
4	Port	12	**12**	15	**7**	26	**28**	7	**5**	1	**0**
5	"	2	**3**	20	**12**	9	**30**	3	**0**	-	-
6	"	15	**8**	8	**4**	11	**12**	2	**2**	-	-
7	"	1	**1**	16	**8**	72	**48**	1	**2**	-	-
8	Stbd	-	-	9	**10**	47	**19**	0	**1**	-	-
9	"	1	**0**	15	**4**	22	**4**	-	-	-	-
10	"	2	**0**	11	**4**	42	**30**	1	**0**	-	-
11	Port	0	**1**	4	**2**	45	**22**	1	**0**	-	-
12	"	1	**0**	12	**13**	120	**44**	0	**1**	-	-
13	"	32	**24**	7	**4**	24	**13**	-	-	1	**0**
14	Stbd	3	**4**	46	**43**	2	**3**	-	-	-	-
15	Port	5	**2**	19	**8**	11	**0**	2	**2**	-	-
16	"	11	**3**	94	**58**	235	**110**	0	**3**	8	**2**
17	Stbd	2	**2**	37	**29**	127	**64**	-	-	3	**3**
18	"	1	**3**	92	**75**	57	**146**	-	-	0	**3**
Totals		150	**110**	436	**301**	1074	**749**	20	**16**	15	**8**

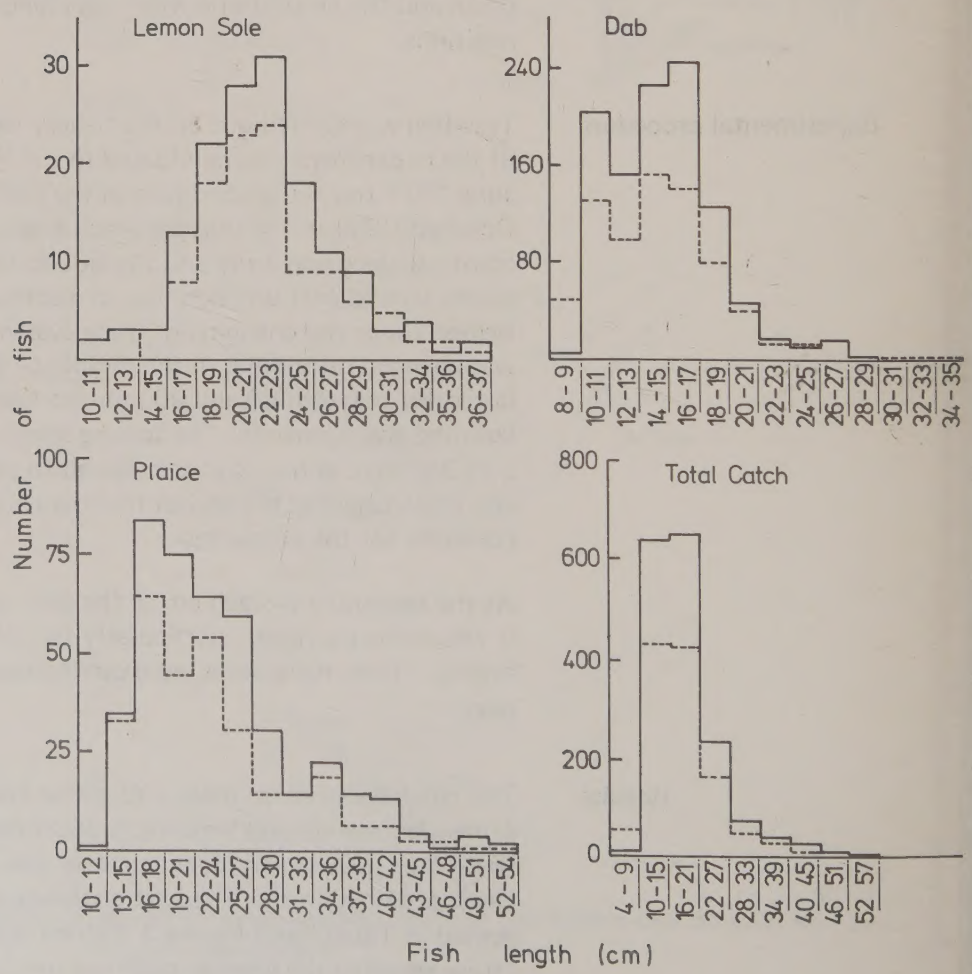

Figure 3. Catch length data for June 1974 cruise.

Table II

Number of fish caught in successive hauls in the Moray Firth during October 1975 (non-electrified catch in bold type)

Haul No	Side Electrified	Plaice		Common Dab	
1	Port	17	**22**	34	**19**
2	"	10	**23**	31	**36**
3	"	39	**41**	44	**34**
4	"	97	**62**	86	**157**
5	"	8	**28**	31	**37**
6	"	2	**11**	3	**9**
7	"	12	**27**	31	**52**
8	"	17	**3**	10	**7**
9	"	11	**18**	15	**40**
10	"	9	**25**	11	**26**
11	"	7	**34**	16	**61**
12	"	10	**45**	39	**52**
13	Stbd	14	**12**	15	**11**
14	"	10	**7**	12	**3**
15	"	69	**39**	64	**50**
16	"	17	**22**	27	**29**
17	"	19	**13**	10	**10**
18	"	22	**26**	28	**36**
19	"	19	**36**	43	**38**
20	"	75	**71**	65	**69**
21	"	9	**12**	23	**11**
22	"	9	**8**	18	**13**
23	"	11	**9**	10	**5**
24	"	19	**11**	32	**14**
25	"	13	**2**	16	**13**
Totals		545	**607**	714	**832**

Table III

Number of fish caught in successive hauls in the Moray Firth during October 1976 (non-electrified catch in bold type)

Haul No	Side Electrified	Plaice		Common Dab	
1	Port	25	**22**	32	**30**
2	"	31	**28**	117	**135**
3	"	34	**16**	81	**44**
4	"	21	**30**	79	**103**
5	"	6	**5**	29	**20**
6	"	19	**63**	33	**56**
7	"	56	**42**	110	**174**
Totals		192	**206**	481	**562**

The catch data for the second part of the experiment, the cruises in October 1975 and October 1976, are given in Tables II and III and Figures 4 and 5, the tables and figures having the same meaning as those for the first part of the experiment. The catch in the second part of the experiment consisted mainly of plaice and common dab. The 'chain' side of the gear always contained more benthic debris than the 'electric' side, which was normally free of debris.

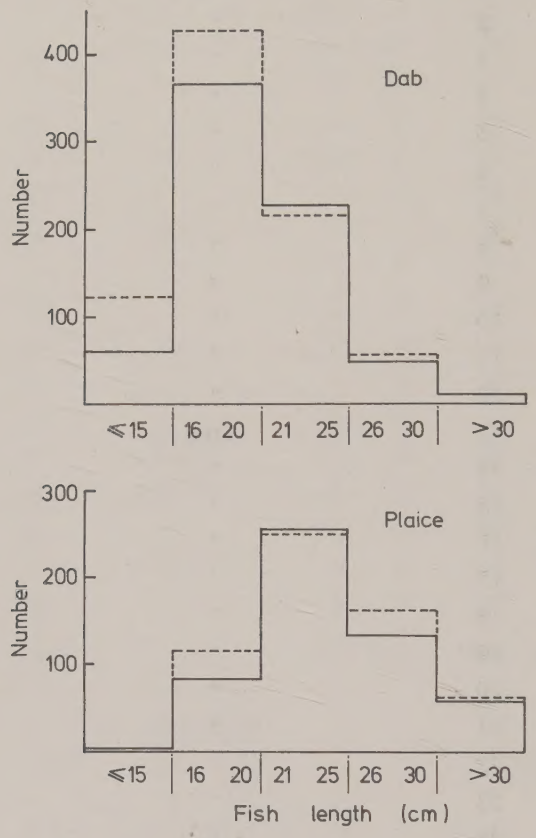

Figure 4. Catch length data for October 1975 cruise.

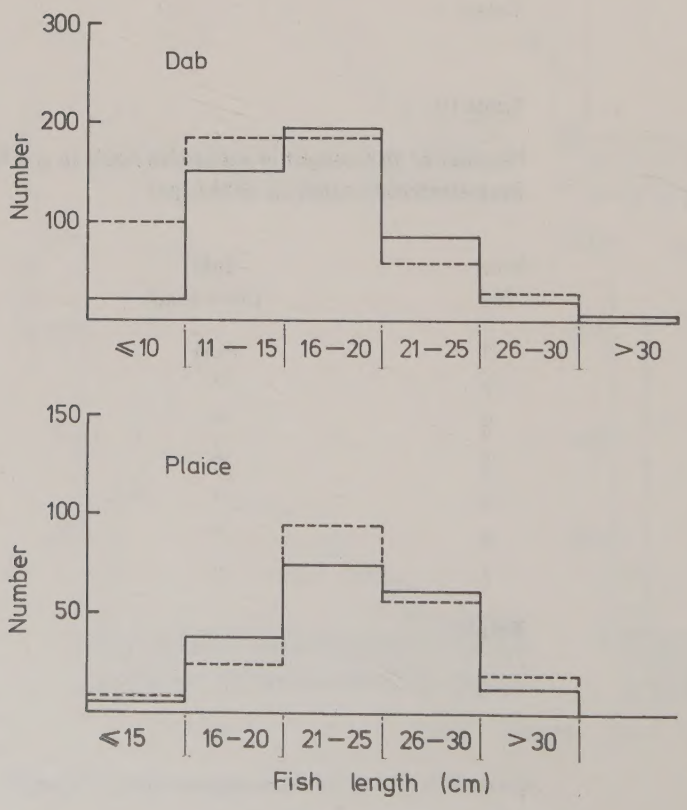

Figure 5. Catch length data for October 1976 cruise.

Analysis of data

In the design and conduct of these experiments and in the analysis of the data due attention was given to the recommendations of the ICES working group on procedures for comparing the performances of different gears (Anon., 1974).

Examination of the data for the first part of the experiment showed that in almost all hauls the electrified side caught more fish than the non-electrified side. The catch data for lemon sole, plaice and common dab were analysed for significance. Because of the skewness of the distrubutions of numbers caught statistical analysis was performed with the data transformed to logarithms The ratio of one catch to another was considered instead of the difference. A t-test showed that the catch ratios were statistically significant in several cases, as shown in Table IV. The results from all length groupings and species were consistent in showing that catches were not significantly different in the port and starboard sides of the net.

Table IV

Ratios of electrified to non-electrified catches obtained in the June 1974 cruise

Species	All Sizes
Lemon Sole	1.28
Plaice	1.58
Common Dab	1.49
Total Catch	1.54

Table V

Ratios of electrified to non-electrified catches obtained a) in the October 1975 cruise, and b) in the October 1976 cruise

	Species	All Sizes
a)	Common Dab	0.97
	Plaice	0.82
b)	Species	All Sizes
	Common Dab	0.95
	Plaice	0.99

The catch obtained in the second part of the experiment consisted mainly of plaice and common dab. A similar analysis was carried out on the data for both cruises. The data from the October 1975 experiment showed that the catches made by the port and starboard sides of the gear were unequal. Eliminating the effect of side on the catch, the ratios of the electrified and chain-tickled catches were evaluated, and these data for plaice and dabs are presented in Table Va. The analysis indicated that the catches obtained by the two systems were not significantly different, and that the electric ticklers were possibly marginally less efficient. Analysis of the size distribution of the catch of common dab showed little evidence of differences between the catches obtained with the two tickler systems, although the catches taken in the starboard half of the gear when it was not electrified contained a high proportion of small fish. This result was, however, very largely due to one haul in which a greater than average number of small fish was taken in the starboard side. No significant differences between the size distributions of the two catches were apparent in the data for plaice.

The data obtained in the October 1976 cruise (the second cruise of the second part of the experiment) were limited, as the cruise lasted only one week. Experimental conditions were the same as in the October 1975 cruise except that in the limited time available the gear configuration was not changed and the same half of the net was electrified in all hauls. The catch consisted mainly of common dab and plaice. As before, the effect of electrification was estimated by evaluating the catch ratios. The ratios are shown in Table Vb, and indicate no significant differences. The size distributions of the aggregated catches for the two species were analysed. The distributions for the electrified and chain tickled catches of dabs were found to be significantly different, the difference being due to the large proportion of small fish caught in the non-electrified half of the gear. The data for plaice did not reveal any significant difference between the catch compositions.

Discussion

The first part of the experiment demonstrated that an electric stimulus attached to a trawl acts as an effective tickler for flatfish. In this part of the experiment the stimulating effect of the electric tickler system was compared with the herding effect of the groundrope on the non-electrified side.

Analysis of the data for the October 1975 cruise, in which electric and chain ticklers were being compared, was complicated by the tendency of the starboard side of the gear to catch more than the port side. It was clear during the cruise that this was occurring, and although the gear was inspected by divers no obvious cause was identified. Since conditions were maintained constant throughout the experiment it was possible to eliminate the effect of side of gear during analysis and demonstrate that the chain and electric ticklers had similar efficiencies. The data for the short October 1976 cruise, in which the gear appeared to be fishing evenly, supported these results. Analysis of the size distribution of the catches obtained in the second part of the experiment suggests that an electric tickler system may catch fewer juvenile fish than a chain tickler system. The preferential capture of small fish by the chain side was noted only in the catches of common dab, the only species of which significant numbers of juveniles were taken during the experiment.

The observations made during this experiment confirm the results of earlier work on the reactions of flatfish to electrical stimulation. The experiments have demonstrated that an electric stimulus is as effective as a 12 mm chain when used on a beam trawl for the capture of flatfish species such as plaice and common dab. The results suggest that the electric stimulus may be more size selective than the chain, but this feature requires further study.

An advantage of an electric tickler system is its light weight, so that replacing chain ticklers by electric ticklers can reduce gear drag and hence towing power. The disadvantage of an electric tickler system is its complexity, rendering it susceptible to damage under the arduous conditions of bottom trawling. Chain is simpler to use but is subject to wear and requires frequent replacement. Chain also dislodges benthic debris, which damages netting, prevents the escape of small fish from the cod-end and makes catch sorting difficult.

The beam trawl appears to be the most suitable gear for conversion to use with electric tickler systems as it provides a strong, secure framework for the underwater electrical equipment. Further, the area to be electrified in a beam trawl is relatively small compared with an otter trawl, thus minimising the size of the electrical equipment and its power demands.

Apart from strictly economic considerations, the replacement of chains by electric tickler systems could influence the fishery for flatfish in other ways.

Firstly, the possible reduction in the mortality of juvenile flatfish could lead to an improvement in the stocks. Secondly, it is possible that regular trawling with chains on a fishing ground has an adverse effect on the bottom fauna.

Acknowledgements

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Summary

Flatfish respond to an electric stimulus by moving away from the electrified zone. Experiment has demonstrated that this reaction is induced most effectively by a pulsed DC field at 20 Hz and that large fish react more strongly than small fish. This behaviour suggested that electric ticklers could usefully replace chain ticklers on flatfish trawls. To investigate this idea two comparative fishing experiments were conducted using a divided beam trawl. In the first experiment one side of the gear was electrified during each haul and it was found that the electric stimulus significantly increased the catch. In the second experiment the non-electrified side of the gear was rigged with a chain tickler, and no significant difference was found between the total catches.

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